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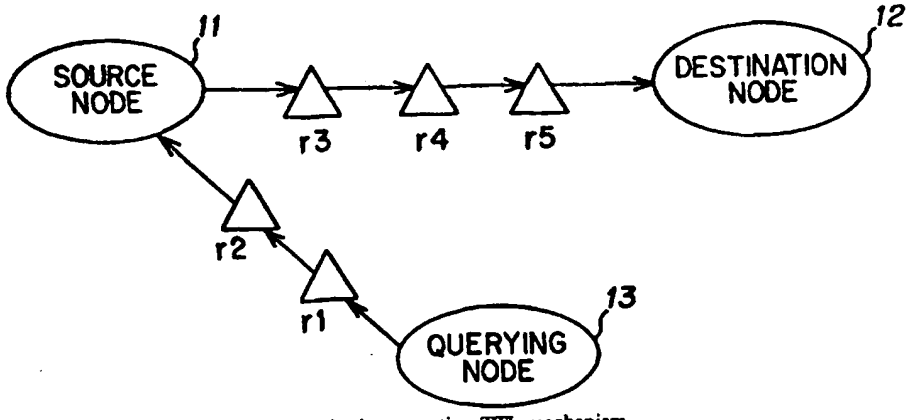
(57) Abstract

Method and apparatus for determining a data path between source (11) and destination (12) IP devices. A TTL mechanism is used, in combination with loose-source routing, to incrementally discover the routers on the path, wherein the querying node (13) sending the UDP probe packets need not be the source node. Once an intermediate router on the path is known which can communicate via SNMP, an SNMP query may be sent to determine the next-hop router from the IP routing table. If this fails, the method reverts to the incrementing TTL mechanism.



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# METHOD AND APPARATUS FOR DETERMINING IP COMMUNICATIONS PATH

## Field of the Invention

This invention relates to computer network communication systems, and in particular to a method and apparatus for determining data paths on an IP network.

## Background of the Invention

In an Internet, several networks are connected together through the use of gateways and an internetworking protocol. The gateways (often called routers), using the protocol, hide the underlying details of the actual networks, in order to provide uniform service across the network.

The leading internetworking technology is the Internet suite of protocols, commonly referred to as TCP/IP, after the two-core protocols in the suite. TCP, the transmission control protocol, is a connection-oriented transport service. IP, the Internet protocol, is a connectionless-mode network service.

IP is called a connectionless-mode network protocol, which means that it is datagram-oriented. When some entity on the network wishes to send data using IP, it sends that data as a series of datagrams. Associated with each datagram is an address indicating where the datagram should be delivered. This address consists of an IP address, an upper-layer protocol number. IP takes the user-data and encapsulates it in an IP datagram, which contains all of the information necessary to deliver the datagram to the IP entity at the destination. The remote IP entity will examine the IP datagram it receives, and then strip off the data and pass it up to the appropriate upper-layer protocol. See, M. Rose, "The Simple Book - An Introduction To Management Of TCP/IP-Based Internets," Prentice Hall, 1991.

SNMP, Simple Network Management Protocol, has become the de facto operational standard for network management of TCP/IP-based internets. A managed network may be considered as consisting of three components: (1) several managed nodes, each containing an agent; (2) at least one network management station

(NMS); and (3) a network management protocol, which is used by the station and the agents to exchange management information. The managed node may consist of a host system, e.g., workstation, terminal server, or printer; a gateway system, e.g., a router; or a media device, e.g., a bridge, hub or multiplexor. One activity of the network management system is to compile a topology of the network, defining the connections between various devices on the network. The network management system may query the IP routing table at each gateway, to determine what devices are located at each port on the gateway. This information may be used to construct a data path between any two devices on the internet.

Associated with IP is another protocol providing low-level feedback about how the internet layer is operating. This protocol is termed the "Internet Control Method Protocol" (ICMP). ICMP provides basic control messages for error reporting.

One useful tool in troubleshooting connectivity problems at the internet layer is a program called "traceroute." The traceroute program sends a series of "probe packets" using UDP to an IP address and awaits an ICMP reply. More specifically, IP datagrams carrying the UDP packets are sent with monotonically increasing values in the "time to live" (TTL) field, and the UDP port chosen is one most likely not to be in use. For each TTL value, the traceroute program sends a fixed number of packets (usually three), and reports back the IP addresses of the devices responding. This process continues until an ICMP port unreachable packet is received or some TTL threshold is reached (usually 30).

If a gateway receives an IP datagram and decrements the TTL to zero, then it returns an ICMP time exceeded packet. If the IP datagram eventually reaches the network device in question, an ICMP port unreachable packet will be returned. Combining the information from all the replies, the traceroute program can report on the whole route. See M. Rose, supra, at 66-67. A copy of the traceroute progam is shown below.

```
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*
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*THIS SOFTWARE IS PROVIDED "AS IS" AND WITHOUT ANY EXPRESS OR
*IMPLIED WARRANTIES, INCLUDING, WITHOUT LIMITATION, THE IMPLIED
*WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR
*PURPOSE.
*/
[7m--More--[m
[;H[2J

#include <stdio.h>
#include <errno.h>
#include <strings.h>
#include <sys/time.h>

#include <sys/param.h>
#include <sys/socket.h>
#include <sys/file.h>
#include <sys/ioctl.h>

#include <netinet/in_systm.h>
#include <netinet/in.h>
#include <netinet/ip.h>
#include <netinet/ip_var.h>
#include <netinet/ip_icmp.h>
#include <netinet/udp.h>
#include <netdb.h>
#include <ctype.h>

#define MAXPACKET 65535 /* max ip packet size */
#ifndef MAXHOSTNAMELEN
#define MAXHOSTNAMELEN 64
[7m--More--[m
[;H[2J
#endif

#ifndef FD_SET
#define NFDBITS         (8*sizeof(fd_set))
#define FD_SETSIZE        NFDBITS
#define FD_SET(n, p)    ((p)->fds_bits[(n)/NFDBITS] |= (1 << ((n)
                          % NFDBITS)))
#define FD_CLR(n, p)    ((p)->fds_bits[(n)/NFDBITS] &= ~(1 <<
                        ((n) % NFDBITS)))
#define FD_ISSET(n, p)  ((p)->fds_bits[(n)NFDBITS] &(1 << ((n) %
                         NFDBITS)))
```

```
#define FD_ZERO(p)      bzero((char *)(p), sizeof(*(p)))
#endif

#define Fprintf (void)fprintf
#define Sprintf (void)sprintf
#define Printf (void)printf

extern   int errno;
extern  char *malloc();
extern  char *inet_ntoa();
extern  u_long inet_addr();

/*
 *format of a (udp) probe packet.
 */
[7m--More--[m
[;H[2J
struct opacket {
        struct ip ip;
        struct udphdr udp;
        u_char seq;             /* sequence number of this packet*/
        u_char ttl;             /* ttl packet left with*/
        struct timeval tv; /* time packet left*/
};

u_char packet[512];              /* last inbound (icmp) packet*/
struct opacket   *outpacket;  /* last output (udp) packet*/
char *inetname();

int s;                           /* receive (icmp) socket file
                                    descriptor*/
int sndsock;                     /* send (udp) socket file
                                    descriptor*/
struct timezone tz;              /* leftover*/

struct sockaddr whereto;    /* Who to try to reach*/
int datalen;                     /* How much data*/

char *source = 0;
char *hostname;
char hnamebuf[MAXHOSTNAMELEN];

[7m--More--[m
[;H[2J
int nprobes = 3;
int max_ttl = 30;
u_short ident;
u_short port = 32768+666;        /* start udp dest port#for probe
                                    packets*/

int options;                     /* socket options */
int verbose;
int waittime = 5;           /* time to wait for response
                               (in seconds)*/
int nflag;                       /* print addresses numerically*/
```

```
char usage[] =
"Usage: traceroute [-dnrv] [-w wait] [-m max_ttl] [-p port#]
[-q nqueries] [-t tos] [-s src_addr] [-g gateway] host [data
size]\n";

main(argc, argv)
     char *argv[];
{
     struct sockaddr_in from;
     char **av = argv;
     struct sockaddr_in *to = (struct sockaddr_in*)&whereto;
     int on = 1;
     struct protoent *pe;
     int ttl, probe, i;

[7m--More--[m
[;H[2J
     int seq = 0;
     int tos = 0;
     struct hostent *hp;
     int lsrr = 0;
     u_long gw;
     u_char optlist[MAX_IPOPTLEN], *oix;

     oix = optlist;
     bzero(optlist, sizeof(optlist));

     argc--, av++;
     while (argc && *av[0] =='_') {
        while (*++av[0])
                switch (*av[0]){
                case 'd':
                        options |= SO_DEBUG;
                        break;
                case 'g':
                        argc--, av++;
                        if ((lsrr+1) >= ((MAX_IPOPTLEN-IPOPT_
                        MINOFF)
                        /sizeof(u_long)))
{
                        Fprintf(stderr,"No more than %/d
                        gateways\n",
                             ((MAX_IPOPTLEN_IPOPT_MINOFF)
                               /sizeof(u_[7m--
More--[m
[;H[2J
long))-1);
                         exit(1);
                         }
                         if (Isrr == 0){
                         *oix++ = IPOPT_LSRR;
                         *oix++;        /* Fill in total
                                           length later*/
     *oix++ = IPOPT_MINOFF; /* Pointer to LSRR addresses*/
                         }
```

```
                        lsrr++;
                        if (isdigit(*av[0])){
                        gw = inet_addr(*av);
                        if (gw) {
                        bcopy(&gw, oix, sizeof(u_long));
                        } else {
                        Fprintf(stderr, "Unknown host
                        %s\n",av[0]);
                        exit(1);
                        }
                        } else {
                        hp=gethostbyname(av[0]);
                        if (hp) {
                        bcopy(hp->h_addr, oix,
                        sizeof(u_long));
                        } else {
[7m--More--[m
[;H[2J

                        Fprintf(stderr, "Unknown host
                        %s\n",av[0]);
                        exit(1);
                        }
                        }
                        oix += sizeof(u_long);
                        goto nextarg;
                case 'm':
                        argc--, av++;
                        max_ttl = atoi(av[0]);
                        if (max_ttl <= 1) {
                                Fprintf(stderr, "max ttl
                                must be >1\n");
        exit(1);
                        }
                        goto nextarg;
                case 'n':
                        nflag++;
                        break;
                case 'p':
                        argc--, av++;
                        port = atoi(av[0]);
                        if (port < 1) {
                                Fprintf(stderr, "port
                                must be >0\n");
                                exit(1);
[7m--More--[m
[;H[2J

                        }
                        goto nextarg;
                case 'q':
                        argc--, av++;
                        nprobes = atoi(av[0]);
                        if (nprobes < 1) {
                                Fprintf(stderr, "nprobes
                                must be >0\n");
        exit(1);
```

```
                        }
                        goto nextarg;
                case 'r':
                        options |= SO_DONTROUTE;
                        break;
                case 's':
                        /*
                         * set the ip source address of
                           the outbound
                         * probe (e.g., on a multi-homed
                           host).
                         */
                        argc--, av++;
                        source = av[0];
                        goto nextarg;
                case 't':
                        argc--, av++;
[7m--More--[m
[;H[2J
                        tos = atoi(av[0]);
                        if (tos < 0 || tos > 255) {
                                Fprintf(stderr, "tos
                                must be 0 to 255\n");
                        exit(1);
                        }
                        goto nextarg;
                  case 'v':
                        verbose++;
                        break;
                  case 'w':
                        argc--, av++;
                        waittime = atoi(av[0]);
                        if (waittime <= 1) {
                                Fprintf(stderr, "wait
                                must be > 1 sec\n");
                                exit(1);
                        }
                        goto nextarg;
        nextarg:
              argc--, av++;
        }
[7m--More--[m
[;H[2J
        if (argc < 1) {
                Printf(usage);
                exit(1);
        }
        setlinebuf (stdout);

        (void) bzero((char *)&whereto, sizeof(struct sockaddr));
        to->sin_family = AF_INET;
        to->sin_addr.s_addr=inet_addr(av[0]);
        if (to->sin_addr.s_addr != -1) {
                (void) strcpy(hnamebuf, av[0]);
                hostname = hnamebuf;
```

```
        } else {
                    hp = gethostbyname(av[0]);
                    if (hp) {
                          to->sin_family = hp->h_addrtype;
                          bcopy(hp->h_addr, (caddr_t)&to->sin_
                          addr, hp-
                          >h_length);
         hostname = hp->h_name;
                    } else {
                          Printf("%s: unknown host %s\n",
                          argv[0], av[0]);
                          exit(1);
                    }
        }
[7m--More--[m
[;H[2J
        if(argc >= 2)
                    datalen = atoi(av[1]);
        if (datalen < 0 || datalen >= MAXPACKET - sizeof
            (struct opacket)) {
                    Fprintf(stderr, "traceroute: packet size
                    must be 0 <= s < %ld\n",
                       MAXPACKET - sizeof(struct opacket));
                    exit(1);
               }
         datalen += sizeof(struct opacket);
         outpacket = (struct opacket
         *)malloc((unsigned)datalen);
         if (! outpacket) {
                   perror("traceroute: malloc");
                   exit(1);
         }
         (void) bzero((char *)outpacket, datalen);
         outpacket->ip.ip_dst = to->sin_addr;
         outpacket->ip.ip_tos = tos;

         ident = (getpid() & 0xffff | 0x8000;

         if ((pe = getprotobyname("icmp")) == NULL){
                    Fprintf(stderr, "icmp: unknown protocol\n");
[7m--More--[m
[;H[2J
                    exit(10);
          }
          if ((s = socket(AF_INET, SOCK_RAW, pe->p_proto)) < 0 {
                     perror("traceroute: icmp socket");
                     exit(5);
          }
      else
     {
           printf ("Opened recv side RAW socket, proto [ICMP]
                    = %d\n",
                   pe->p_proto);
      }
           if (options & SO_DEBUG)
```

```
                        (void) setsockopt(s, SOL_SOCKET,SO_DEBUG,
                                          (char *)&on,sizeof(on));
                if (options & SO_DONTROUTE)
                        (void) setsockopt(s, SOL_SOCKET,
                        SO_DONTROUTE,
                                          (char *)&on,sizeof(on));

                if ((sndsock = socket(AF_INET, SOCK_RAW,IPPROTO_RAW))
                      < 0) {
                        perror("traceroute: raw socket");
                        exit(5);
    [?1h=       }
          else
    [7m--More--[m
    [;H[2J
          {
            printf ("Opened send side RAW socket,proto=IPPROTO_RAW
                    \n");
          }

              if (lsrr > 0) {
                lsrr++;
                optlist[IPOPT_OLEN]=IPOPT_MINOFF-1+(lsrr*sizeof
                (u_long));
       printf ("optlist[IPOPT_OLEN] = %d\n", optlist[IPOPT_OLEN]);

                bcopy((caddr_t)&to->sin_addr, oix,
                sizeof(u_long));
                oix += sizeof(u_long);
                while ((oix - optlist)&3) oix++;    /* Pad to an
                                                       even
                                                       boundry*/

    hex_display (optlist, (optlist[IPOPT_OLEN] + 4));

               if ((pe = getprotobyname("ip")) == NULL) {
                  perror("traceroute: unknown protocol ip\n");

                exit(10);
               }
               if ((setsockopt(sndsock, pe->p_proto,
                     IP_OPTIONS, optlist,oix-optlist)) < 0){
    [7m--More--[m
    [;H[2J
                perror("traceroute: lsrr options");
                exit(5);
               }
             else
            {
             printf ("Set IP_OPTIONS (for loose routing), proto
             used=%d\n",
                    pe->p_proto);
              }
                }
```

```
#ifdef SO_SNDBUF

        printf ("Using setsockopt SOL_SOCKET, SO_SNDBUF,\n");

          if (setsockopt(sndsock, SOL_SOCKET, SO_SNDBUF,
          (char*)&datalen,
                    sizeof(datalen)) < 0) {
                      perror("traceroute: SO_SNDBUF");
                      exit(6);
      }
#endif SO_SNDBUF
#ifdef IP_HDRINCL

     printf ("IP_HDRINCL defined \n");
[7m--More--[m
[;H[2J

        if (setsockopt(sndsock, IPPROTO_IP, IP_HDRINCL,
        (char *)&on,
                        sizeof(on)) < 0) {
                    perror("traceroute: IP_HDRINCL");
                    exit(6);
        }
#endif IP_HDRINCL
         if (options & SO_DEBUG)
        (void) setsockopt(sndsock, SOL_SOCKET, SO_DEBUG,
                          (char *)&on, sizeof(on));
        if (options & SO_DONTROUTE)
                    (void) setsockopt(sndsock, SOL_SOCKET,
                     SO_DONTROUTE,
                          (char *)&on, sizeof(on));
        if (source) {
              (void) bzero((char *)&from, sizeof(struct
               sockaddr));
               from.sin_family = AF_INET;
               from.sin_addr.s_addr == inet_addr(source);
               if (from.sin_addr.s_addr == -1) {
                          Printf("traceroute: unknown host
                          %s\n", source);
                          exit(1);
                  }
                 outpacket->ip.ip_src = from.sin_addr;

[7m--More--[m
[;H[2J
#ifndef IP_HDRINCL

         if (bind(sndsock, (struct sockaddr *)&from, sizeof
        (from)) < 0) {
     perror ("traceroute: bind:");
                    exit (1);
            }
#endif IP_HDRINCL
        }
```

```
        Fprintf(stderr, "traceroute to %s (%s)", hostname,
                    inet_ntoa(to->sin_addr));
        if(source)
                    Fprintf(stderr, " from %s", source);
         Fprintf(stderr, ", %d hops max, %d byte packets\n",
         max_ttl, datalen);
          (void) fflush(stderr);

        for (ttl = 1; ttl <= max_ttl; ++ttl) {
                    u_long lastaddr = 0;
                    int got_there = 0;
                    int unreachable = 0;

                    Printf("%2d", ttl);
                    for (probe = 0; probe < nprobes; ++probe){
[7m--More--[m
[;H[2J
                                int cc;
                                struct timeval tv;
                                struct ip *ip;

                                (void) gettimeofday(&tv, &tz);
                                send_probe(++seq, ttl);
                                while (cc = wait_for_reply(s,
                                      &from)){
                                     if ((i = packet_ok(packet, cc,
                                          &from, seq))) {
                                          int dt = deltaT(&tv);
                                           if (from.sin_addr.s_
                                                addr !
                                                = lastaddr) {
                                                print(packet,
                                                cc, &from);
                                                lastaddr =
                                                from.sin_
                                                addr.s_addr;
                    }
                                           Printf(" %d ms",
                                                 dt);
                                           switch(i - 1) {
                                          case ICMP_UNREACH_
                                          PORT:
    #ifndef ARCHAIC
                                                 ip = (struct
                                                 ip *) packet;
                                                 if (ip->ip_ttl
                                                      <= 1)
                                                 Printf("!");
    #endif ARCHAIC
                                                  ++got_there;
                                                 break;
    [7m--More--[m
    [;H[2J
                                          case ICMP_UNREACH_NET:
                                                 ++unreachable;
```

```
                                        Printf(" !N");
                                        break;
                                case ICMP_UNREACH_HOST:
                                        ++unreachable;
                                        Printf(" !H");
                                        break;
                                case ICMP_UNREACH_
                                PROTOCOL:
                                        ++got there;
                                        Printf(" !P");
                                        break;
                                case ICMP_UNREACH_
                                NEEDFRAG:
                                        ++unreachable;
                                        Printf(" !F");
                                        break;
                                case ICMP_UNREACH_
                                SRCFAIL:
                                        ++unreachable;
                                        Printf("!S");
                                        break;
                                }
                                break;
                        }
[7m--More--[m
[;H[2J
                }
                if (cc ==0)
                        Printf("*");
                (void) fflush(stdout);
        }
        putchar('\n');
        if (got_there || unreachable >= nprobes-1)
                exit(0);
    }
}

wait_for_reply(sock, from)
        int sock;
        struct sockaddr_in *from;
{
        fd_set fds;
        struct timeval wait;
        int cc = 0;
        int fromlen = sizeof (*from);

        FD_ZERO(&fds);
        FD_SET(sock, &fds);
        wait.tv_sec = waittime; wait.tv_usec = 0;
[7m--More--[m
[;H[2J

        if (select(sock+1, &fds, (fd_set *)0, (fd_set *)0,
         &wait) > 0)
                cc--recvfrom(s, (char *)packet,
```

```
                    sizeof(packet), 0,
                                (struct sockaddr *)from,
                                 &fromlen);

        return(cc);
}

send_probe(seq, ttl)
{
        struct opacket *op = outpacket;
        struct ip *ip = &op->ip;
        struct udphdr *up = &op->udp;
        int i;

        ip->ip_off = 0;
        ip->ip_p = IPPROTO_UDP;
        ip->ip_len = datalen;
        ip->ip_ttl = ttl;

        up->uh_sport = htons(ident);
        up->uh_dport = htons(port+seq);
        up->uh_ulen = htons((u_short)(datalen - sizeof(struct
        ip)));
[7m--More--[m
[;H[2J
        up->uh_sum = 0;

        op->seq = seq;
        op->ttl = ttl;
        (void) gettimeofday(&op->tv, &tz);

        i = sendto(sndsock, (char *)outpacket, datalen, 0,
        &whereto,
                        sizeof(struct sockaddr));
        if (i < 0 || i != datalen) {
                if (i<0)
                        perror("sendto");
        Printf("traceroute: wrote %s %d chars, ret=%d\n", hostname,
                datalen, i);
        (void) fflush(stdout);
      }
}

deltaT(tp)
        struct timeval *tp;
{
        struct timeval tv;

        (void) gettimeofday(&tv, &tz);
[7m--More--[m
[;H[2J
        tvsub(&tv, tp);
        return (tv.tv_sec* 1000 + (tv.tv_usec + 500)/1000);
}
```

```
/*
 * Convert an ICMP "type" field to a printable string.
 */
char*
pr-type(t)
        u_char t;
{
     static char *ttab[] = {
     "Echo Reply",     "ICMP 1",     "ICMP 2",           "Dest
     Unreachable",
     "Source Quench", "Redirect"    "ICMP 6",           "ICMP 7",
     "Echo",           "ICMP 9",    "ICMP 10"           "Time
     Exceeded",
     "Param Problem", "Timestamp", "Timestamp Reply", "Info
     Request",
     "Info Reply"
     };

          if(t > 16)
                    return("OUT-OF-RANGE");

          return(ttab[t]);
[7m--More--[m
[;H[2J
}

packet_ok(buf, cc, from, seq)
        u_char *buf;
        int cc;
        struct sockaddr_in *from;
        int seq;
{
        register struct icmp *icp;
        u_char type, code;
        int hlen;
#ifndef ARCHAIC
        struct ip *ip;

        ip = (struct ip *) buf;
        hlen = ip->ip_hl << 2;
        if (cc < hlen + ICMP_MINLEN){
                    if(verbose)
                            Printf("packet too short (%d bytes)
                                from %s\n", cc,
                                      inet_ntoa(from->sin_addr));
                    return (0);
        }
        cc -= hlen;
[7m--More--[m
[;H[2J
        icp = (struct icmp *)(buf + hlen);
#else
        icp = (struct icmp *)buf;
#endif ARCHAIC
        type = icp->icmp_type; code = icp->icmp_code;
```

```
        if((type == ICMP_TIMXCEED && code == ICMP_TIMXCEED_
                INTRANS ||
          type == ICMP_UNREACH){
                struct ip *hip;
                struct udphdr *up;

                hip = &icp->icmp_ip;
                hlen = hip->ip_hl << 2;
                up = (struct udphdr *)((u_char *)hip + hlen);
                if (hlen + 12 <= cc && hip->ip_p ==
                    IPPROTO_UDP &&
                up->uh_sport == htons(ident) &&
                up->uh_dport == htons(port+seq))
                      return (type == ICMP_TIMXCEED? -1 :
                              code+1);
        }
#ifndef ARCHAIC
        if (verbose){
                int i;
                u_long *lp = (u_long *)&icp->icmp_ip;

[7m--More--[m
[;H[2J
                Printf("\n%d bytes from %s to %s", cc,
                        inet_ntoa(from->sin_addr), inet_ntoa
                      (ip->ip_dst));
                Printf(": icmp type %d (%s) code %d\n", type,
                        pr_type(type),
                       icp->icmp_code);
                for (i = 4; i < cc; i += sizeof(long))
                         Printf("%2d: x%8.81x\n", i, *lp++);
        }
#endif ARCHAIC
        return(0);
}

print(buf, cc, from)
        u_char *buf;
        int cc;
        struct sockaddr_in *from;
      {
        struct ip *ip;
        int hlen;

        ip = (struct ip *) buf;
        hlen = ip->ip_hl << 2;
        cc -= hlen;

 [7m--More--[m
 [;H[2J
        if (nflag)
                Printf(" %s", inet_ntoa(from->sin_addr));
        else
                Printf(" %s (%s)", inetname(from->sin_addr),
                      inet_ntoa(from->sin_addr));
```

```
        if (verbose)
                Printf (" %d bytes to %s", cc, inet_ntoa
                (ip->ip_dst));
}

#ifdef notyet
/*
 * Checksum routine for Internet Protocol family headers
    (C Version)
 */
in_cksum(addr, len)
u_short *addr;
int len;
{

        register int nleft.= len;
        register u_short *w = addr;
        register u_short answer;
        register int sum = 0;

[7m--More--[m
[;H[2J
            /*
             * Our algorithm is simple, using a 32 bit
             * accumulator (sum),we add sequential 16 bit words
             * to it, and at the end, fold back all the carry
             * bits from the top 16 bits into the lower 16 bits.
             */
             while (nleft > 1) {
                     sum += *w++;
                     nleft -= 2;
        }

        /* mop up an odd byte, if necessary */
        if (nleft == 1)
                     sum += *(u_char *)w;

       /*
        * add back carry outs from top 16 bits to low 16 bits
        */
        sum = (sum >> 16) + (sum & 0xffff);      /* add hi 16 to
                                                    low 16*/
        sum += (sum >> 16);                      /* add carry */
        answer = ~sum;                           /* truncate to
                                                    16 bits*/
        return (answer);
}

[7m--More--[m
[;H[2J
#endif notyet

/*
 *Subtract 2 timeval structs: out=out - in.
 * Out is assumed to be >= in.
```

```
 */
tvsub(out, in)
register struct timeval *out, *in;
{
        if ((out->tv_usec -= in->tv_usec) < 0) {
                out->t_sec--;
                out->tv_usec += 1000000;
        }
        out->tv_sec -= in->tv_sec;
}

/*
 * Construct an Internet address representation.
 * If the nflag has been supplied, give
 * numeric value, otherwise try for symbolic name.
 */
char

inetname(in)
[7m--More--[m
[;H[2J
        struct in_addr in;
{
        register char *cp;
        static char line[50];
        struct hostent *hp;
        static char domain[MAXHOSTNAMELEN + 1];
        static int first = 1;

        if (first && !nflag){
                first = 0;
                if (gethostname(domain, MAXHOSTNAMELEN)
                    ==0 &&
                   (cp = index(domain, !!)))
                       (void) strcpy(domain, cp + 1);
              else
                       domain[0] = 0;
        }
        cp = 0;
        if (!nflag && in.s_addr!= INADDR_ANY){
                hp = gethostbyaddr((char *)&in, sizeof (in),
                     AF_INET);
                if (hp){
                     if ((cp = index(hp->h_name, '.'))&&
                         !strcmp(cp + 1, domain))
                              *cp = 0;
[7m--More--[m
[;H[2J
                cp = hp->h_name;

             }
        }
        if (cp)
             (void) strcpy(line, cp);
        else {
```

```
                in.s_addr = ntohl(in.s_addr);
#define C(x)     ((x) & 0xff)
                Sprintf(line, "%lu.%lu.%lu.%lu",
                C(in.s_addr >> 24),
                     C(in.s_addr >> 16), C(in.s_addr >> 8),
                     C(in.s_addr));
        }
        return (line);
}

hex_display (ptr, how_much)
unsigned char * ptr;
int how_much;
{
   int i;

   for (i=0; i < how_much; i++)
   {
     if((i % 8) == 0)
[7m--More--[m
[;H[2J
             {
        printf ("\n");
        }
       printf ("%4x", ptr[i]);
      }

   printf ("\n");
}
```

---------- end traceroute.c ----------

Unfortunately, traceroute does not provide any information about which ports of the routers are on the path. In addition, not all devices on the network support IP options needed to implement traceroute.

An SNMP query to a router is another method for tracing a route, i.e., by determining the next-hop router on the current router IP routing table. Unfortunately, not all routers can be accessed by SNMP.

It would thus be desirable to provide a method of tracing a route from any source to any destination, regardless of whether one router is known, and regardless of whether each router on the path can be accessed using SNMP.

Summary of the Invention

The present invention is a method and apparatus for determining a communications path between a source node and a destination node on a network using IP. The method includes compiling a path list of IP addresses for next-hop routers on the path between the source IP address and the destination IP address.

In its broadest sense, the method includes the steps of: (a) sending a series of UDP probe packets out a socket of a first node to find successive next-hop routers on the path; (b) setting the socket of the first node to "loose route" the UDP probe packets through the source IP address; and (c) recording in the path list the next-hop router IP address returned following each one of the series of UDP probe packets. The UDP probe packets have a destination field set with the destination IP address. The time to live (TTL) field of the UDP probe packet is set with an initial value of one, and monotonically increased (i.e., incremented by one) to find each successive next-hop router until the destination is reached.

In a further embodiment, the method includes the step of alternatively sending an SNMP query to a router on the path in order to find the next-hop router on the path. Then, if the SNMP query fails, the method reverts to sending the next UDP probe packet. Thus, if a specific router on the path is discovered and can accept SNMP messages, we can then read its routing table to find out the next router on the way to the destination. The routing table also provides the port which leads to the next router.

In a still further embodiment, if both the UDP probe packet and/or SNMP query fail to provide the next-hop router IP address, then an unknown next-hop router IP address is selected and recorded in the path list. We later use a topology information database from a network management system to resolve this unknown router.

In a still further embodiment, the method includes sending a query to a topology information database to determine any unknown next-hop router IP addresses, as well as any

intra-router (i.e., layer-2 devices, such as hubs, bridges, etc.) on the path.

In this manner, we can determine a complete route from a source node to a destination node. Apparatus for implementing the method is further provided, including a station with a memory and processor for storing and running the traceroute program and/or a network management station for maintaining a management database and sending SNMP queries to various routers on the network which are SNMP compatible.

## Brief Description of the Figures

FIG. 1 is a schematic diagram of a portion of a network in which there is a source node, a destination node, and a querying node.

FIG. 2 is a flowchart illustrating a mechanism by which the distance, in TTL units, is determined between the querying node and the source node.

FIG. 3 is a flowchart illustrating a mechanism for locating the next-hop router along the path from the source node to the destination node using TTL.

FIG. 4 is a flowchart illustrating the overall mechanism for locating the next router utilizing either an SNMP query or UDP probe packet.

FIG. 5 is a block diagram of a general purpose computer, for implementing the various path determination methods of this invention.

## Detailed Description

FIG. 1 illustrates a general example, where there is a source node 11, a destination node 12, and a querying node 13. Additionally, there are routers r1 and r2 between the querying node 13 and the source node 11, and routers r3, r4 and r5 between the source node 11 and destination node 12. This representative network will be used to illustrate the method of the present invention.

In a first incremental TTL mechanism, illustrated in FIG. 2, we set a socket in query node 13, used for sending the

UDP probe packets, to "loose route" all packets through the source node 11. In this manner, we determine the number of routers between the querying node 13 and the source node 11, i.e., r1 and r2.

Once we know one router on the path, i.e., by the above incremental TTL mechanism, we can send an SNMP query to read its routing table to find out the next router on the path for the destination, along with the port which takes us to the next router. If this fails, we revert to the incremental TTL mechanism to find the next-hop router. If both fail, we still continue, adding an unknown router to the path list. Our subsequent discovery of a network management system topology database, e.g., the Spectrum™ program sold by Cabletron Systems, Inc. of Rochester, New Hampshire, may enable us to determine all unknown router nodes as well as identify any intra-router devices on the path.

More specifically, FIG. 2 illustrates the "how_far_is source(source, dest)" portion of our program. In step 21, we set the "loose-source routing" IP option on the socket through which we are sending the UDP packets out. The source is the loose route we specify to the socket. Thus, all packets going through this socket will be routed through this loose route, i.e., source. See D. Comer, "Internetworking With TCP/IP, Vol. I, Principles, Protocols, And Architecture," Prentice Hall, 2nd ed., pp. 103-104 (1991). In step 22, we initialize by setting ttl = 1, and in step 23 we send a UDP probe packet to the destination where TTL = ttl. In step 24 we wait for the TTL EXCEEDED ICMP message. If this message is received from the source, then we return(ttl). If not, in step 25 we increment ttl by one and send another UDP probe packet.

If we are unable to contact a router with an SNMP query, or if we choose to continue using the TTL mechanism, we then utilize the "find_next_hop_using_ttl(source, dest, ttl)" portion of our program illustrated in FIG. 3. Again, in step 51 we send a UDP probe packet to the destination with TTL = ttl and in step 52 we wait for one of the following ICMP responses: TTL EXCEEDED, or PORT_UNREACHABLE. If the message TTL_EXCEEDED is

received, this message has come from one of the intermediate hosts and in step 53 we set IP address = sender of the ICMP message and record its IP address in our path list. If in step 54 no response is received within a designated time period, in step 55 we increment the retry_count and send another UDP probe packet (return to step 51). If (in step 54) we have reached the maximum period, i.e., MAX_RETRY, then we set the IP address to an unknown IP address (step 56) and enter the same in the path list.

If a PORT_UNREACHABLE message is received (step 57), this message can only come from the destination and therefore we enter the IP address of the destination in our path list and we are finished.

FIG. 4 illustrates generally a preferred method in which we first try an SNMP search 31 (assuming we have a known router), and if it is successful (step 32), we continue to increment TTL (step 34) and then return to conduct an SNMP search (step 31) on the next-hop router. If the SNMP search is not successful, we send (step 33) a UDP probe packet to determine the next-hop router. If this is successful (step 35), we again increment TTL (step 34) and then conduct an SNMP search on the next-hop router. If the UDP probe packet search is not successful, we add (step 36) an unknown router address to our path list and then increment TTL (step 34). Once we have reached the destination, we can then query our management database (i.e., Spectrum™)(step 37) to determine all the intra-router devices, i.e. layer-2 devices including hubs, bridges, etc., between each pair of routers discovered previously. We can also use the management database to try to resolve the unknown router nodes in the path list. Essentially, we use management database's knowledge of how the various device models are connected to each other. For example, Spectrum™ acquires this knowledge during an "autodiscovery" process of all the devices on the network. The Spectrum™ network management platform

is described in U.S. Patent No. 5,261,044 and in copending and commonly owned U.S. Serial No. 07/797,121 filed November 22,

1991 by R. Dev et al., which are hereby incorporated by reference in their entirety. Spectrum™ implements the Autodiscovery process described in copending and commonly owned U.S. Serial No. 08/115,232 filed September 1, 1993 by T. Orr et al., which is also incorporated by reference in its entirety. The present invention is not limited to use of the Spectrum™ database, but contemplates the use of any such topology database which defines the relative location of devices on the network.

The program may be implemented in a general purpose computer 41 such as shown in FIG. 5. As can be seen, the general purpose computer includes a computer processing unit (CPU) 42, memory 43, a processing bus 44 by which the CPU can access the memory, and access to a network 45.

The following code can be used to illustrate the method of this invention:

```
discover_ip_path (source, dest)
(
//Variables used:
//
//  source    :  user specified source IP address
//  dest      :  user specified destination IP address
//  curr_ttl  :  this will be used to find the next
                 router when the TTL mechanism is
                 used.
//  path_list:   list used for storing the discovered
                 path

    sending-socket = open a RAW socket to send out
    the UDP probe packets.

  if (source is same as the station running this
  application)
  (
     curr_ttl = 0
  )
  else
```

```
(
  Set the sending-socket to loose-route UDP probe
  packets through the source.  This will be used in
  "how_far_is_source" and "trace_next_hop_using_
  ttl" calls below.

  curr_ttl = how_far_is_source (source, dest)

)

curr_node = source
path_list = empty list.
while (curr_node != dest)
(
   next_hop = NULL

if (curr_node is a router and Spectrum has a SNMP
model for it)
(
  next_hop = trace_next_hop_using_snmp (dest.
  curr_node)
)
if (! next_hop) // SNMP method failed.  Let's try
TTL method.
(
  next_hop = trace_next_hop_using_ttl (dest, curr_
  ttl);
)
if (! next_hop) // Even the TTL method failed.
(
   path_list->add (unknown_router);
)
else
(
   path_list->add (next_hop)
)
curr_ttl++       // increment curr_ttl
```

```
    curr_node = next_hop
    )
    phase_2_discovery (path_list);
  )
how_far_is_source (source, dest)
  (
      Use incremental TTL value program to find out how many hops
      away is the source from the station
      running this program.
      Note:  that all UDP packets used herein originate from the
      station running this program and are destined for dest.
      The loose-routing option set above will force these packets
      to take following path:
      source ------------>dest

      application running this program
  )
  trace_next_hop_using_ttl (dest, curr_ttl)
  (
      Sending-socket is already set to loose-route the
      packets through source.
      send a UDP probe packet to dest with TTL value
      equal to (curr_ttl+1) and wait for the ICMP TTL_
      EXPIRED message.
      This message will come from the next router we
      are looking for.
  )
  trace_next_hop_using_snmp (dest, curr_node)
  (
      This method uses SNMP queries to find out the next node in
      the path.  IP routing table is read from the curr_node to
      find out the next hop for the given destination.

      If the dest address is a.b.d.c., we try to read the next
      hop values for the following addresses (in this order)
      until one succeeds:
         a.b.c.d
```

a.b.c.0
a.b.0.0
a.0.0.0

If the next hop value is successfully found, we also return the corresponding port information (i.e. port of curr_node which connects to the next-hop).

The following is an example of an SNMP routing table:

| Destination | Next-Hop | Out_port |
|---|---|---|
| 134.141.1.0 | via 134.141.150.251 | Ethernet1 |
| 134.141.7.0 | via 134.141.150.251 | Ethernet1 |
| 134.141.6.0 | via 134.141.150.251 | Ethernet1 |
| 134.141.159.0 | via 134.141.155.254 | Serial0 |
| 134.141.153.0 | directly connected | Ethernet0 |
| 134.141.152.0 | directly connected | Ethernet1 |

If a search of the IP routing table fails to find the next hop, it returns an invalid IP address. This causes the "discover_ip_path ()" method to use the "find_next_hop_using_TTL ()" method to find the next hop.

Example

The following example illustrates a method of the invention in accordance with the representative network shown in FIG. 1.

In this example, arrows show the path the UDP probe packets are going to take.

querying: the node running this program
source: given source IP address
dest: given dest IP address

r1, r2: routers between querying node and source
r3, r4, r5: routers between source and dest

The socket used for sending the UDP probe packets from the querying node is set to loose-route all packets through source.

Also, all the UDP probe packets are sent to dest on an unused destination port number, so that if the probe reaches the dest, the dest will send us back a PORT_UNREACHABLE ICMP message.

how_far_is_source (source, dest)

For ttl=1, r1 will send the TTL_EXCEEDED ICMP message,
for ttl=2, r2 will send the TTL_EXCEEDED ICMP message
for ttl=3, source will send the TTL_EXCEEDED ICMP message

and this method will return 3.

subsequent discovery

The subsequent discovery will depend on whether we have SNMP models for source, r3, r4 and r5 etc. in our Spectrum™ database, e.g.,

r3 will be discovered by reading the routing table from the source or using the TTL mechanism with TTL=4

r4 will be discovered by reading the routing table from r3 or using the TTL mechanism with TTL=5

Similarly r5 will be discovered by reading the routing table from r4 or using the TTL mechanism with TTL=6

Finally, we will know that dest is directly connected to r5, either by reading a direct routing entry for dest from r5, or using TTL mechanism (TTL=7) we will receive a PORT_UNREACHABLE ICMP message from the dest.

Having thus described a particular embodiment of the invention, various alterations, modifications and

improvements will readily occur to those skilled in the art. Accordingly, the foregoing description is by way of example only, and not intended to be limiting. The invention is limited only as defined in the following claims and the equivalents thereto.

## CLAIMS

1. A method for determining a path list of IP addresses for next-hop routers on a path between a source IP address and a destination IP address, the method comprising the steps of:

sending a series of UDP probe packets out a socket of a querying node to find successive next-hop routers on the path, the UDP probe packets having a destination field set with the destination IP address and a TTL field set with an initial value of one and being monotonically incremented to find each successive next-hop router until the destination is reached;

setting the socket of the querying node to loose route the UDP probe packets through the source IP address; and

recording in the path list the next-hop router IP address returned following each one of the series of UDP probe packets.

2. The method of claim 1, further including sending an SNMP query to a router on the path in order to find the next-hop router on the path, and if the SNMP query fails, reverting to sending the next UDP probe packet.

3. The method of claim 2, further including if the UDP probe packet fails to provide the next-hop router IP address, selecting an unknown next-hop router IP address to record in the path list.

4. The method of claim 3, further including sending a query to a topology information database to determine any unknown next-hop router IP addresses and any intra-router devices on the path.

5. A method for determining a communications path between a source and a destination on a network using IP, comprising the steps of:

a. determining a current router on the communications path; and

b. determining a next router on the communications path from the current router on the communications path, including the steps of:

b(i) determining the next router via an SNMP query of the current router;

b(ii) determining the next router by sending a UDP probe packet when an SNMP query fails to indicate the next router.

6. The method of claim 5, further including the step of:

c. iterating step b. until the the next router is determined to be the destination.

7. The method of claim 5, wherein step a. further including the steps of:

a(i) setting a TTL value to 1;

a(ii) sending a UDP probe packet with the TTL value to the source;

a(iii) awaiting receipt of a TTL_EXCEEDED ICMP message from a current router;

a(iv) determining the IP address of the current router; and

a(v) incrementing TTL, and repeating steps a(ii), a(iii), and a (iv) until the TTL_EXCEEDED ICMP message is received from the source.

8. The method of claim 5, wherein step b(i) includes the steps of:

b(i)(1) querying the current router for a routing table; and

b(i)(2) determining the next router from the routing table.

9. The method of claim 5, wherein step b(ii) further includes the steps of:

b(ii)(1) setting a TTL value to one plus the number of routers, including the source as a router, between a querying node and the current router;

b(ii)(2) sending a UDP probe packet with the TTL value to the destination through the source, with loose source routing specified;

b(ii)(3) awaiting receipt of a TTL_EXCEEDED ICMP message;

b(ii)(4) determining the IP address of the next router; and

b(ii)(5) incrementing TTL, and repeating steps b(ii)(2)-(4) until the TTL_EXCEEDED ICMP message is received from the destination.

10. The method of claim 5, wherein step b. includes the step of adding the next router to a path list.

11. An apparatus for determining a communications path between a source and a destination on a network using IP, comprising:

means for determining a router on the communications path;

means for determining a next router on the communications path from a current router on the communications path;

wherein the means for determining a next router includes:

means for determining the next router via an SNMP query; and

means for determining the next router by sending a UDP probe packet when an SNMP query fails to indicate the next router.

12. The apparatus of claim 11, further including:

means for iterating the means for determining a next router until the the next router is determined to be the destination.

13. An electronic storage media, containing data representing a computer program, wherein the electronic storage media, when connected with a general purpose computer, comprises:

means for determining a current router on a communications path from a source to a destination;

means for determining a next router on the communications path from a current router on the communications path, including:

means for determining the next router via an SNMP query;

means for determining the next router by sending a UDP probe packet when an SNMP query fails to indicate the next router;

means for iterating the means for determining the next router until the next router is determined to be the destination.

1/3

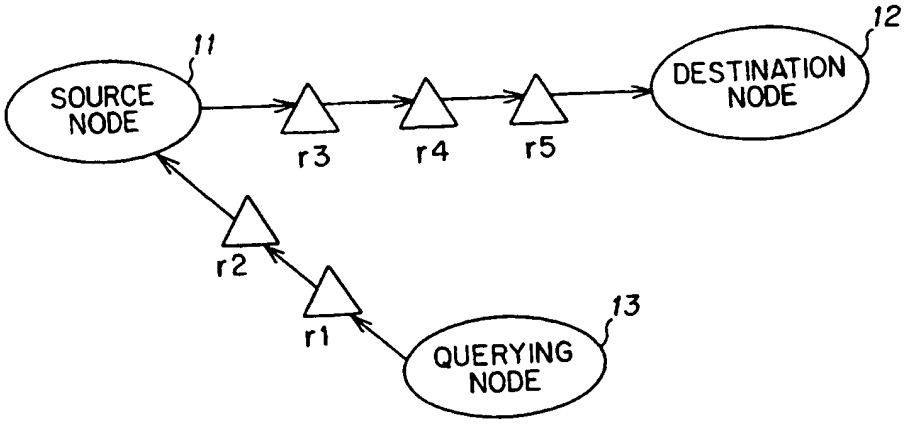
11
SOURCE NODE
r3
r4
r5
12
DESTINATION NODE
r2
r1
13
QUERYING NODE

FIG. 1

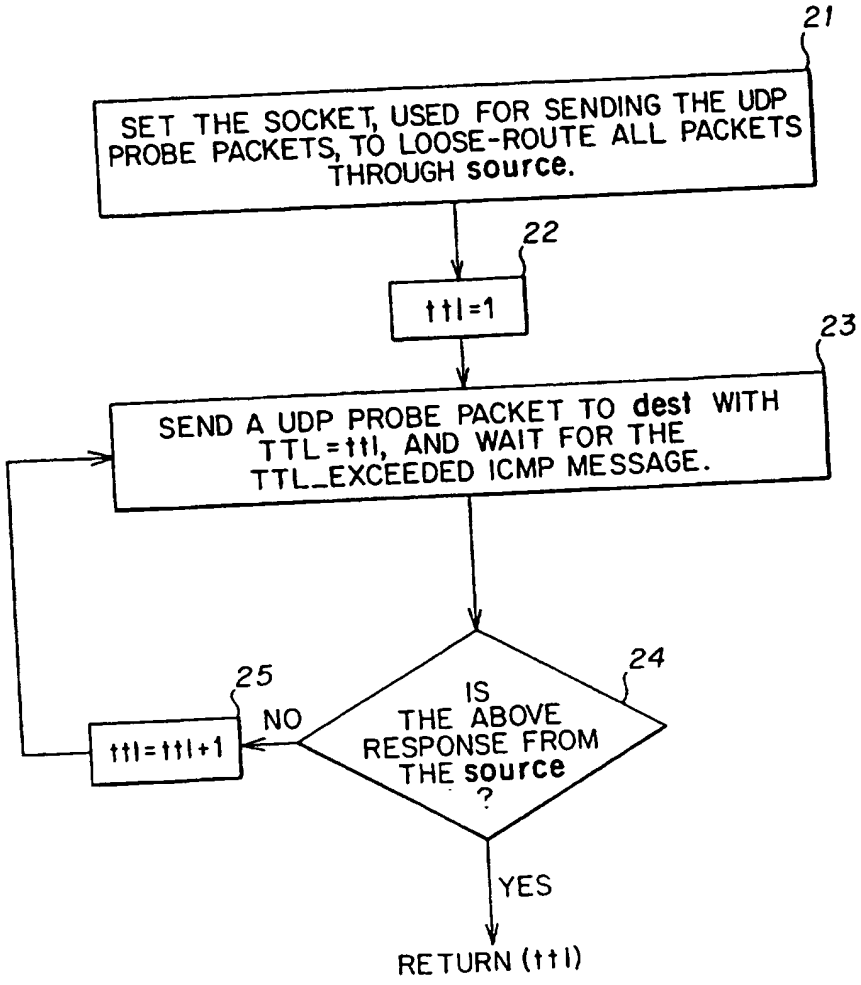
21
SET THE SOCKET, USED FOR SENDING THE UDP PROBE PACKETS, TO LOOSE-ROUTE ALL PACKETS THROUGH source.
22
ttl=1
23
SEND A UDP PROBE PACKET TO dest WITH TTL=ttl, AND WAIT FOR THE TTL_EXCEEDED ICMP MESSAGE.
24
IS THE ABOVE RESPONSE FROM THE source ?
25
NO
ttl=ttl+1
YES
RETURN (ttl)

FIG. 2

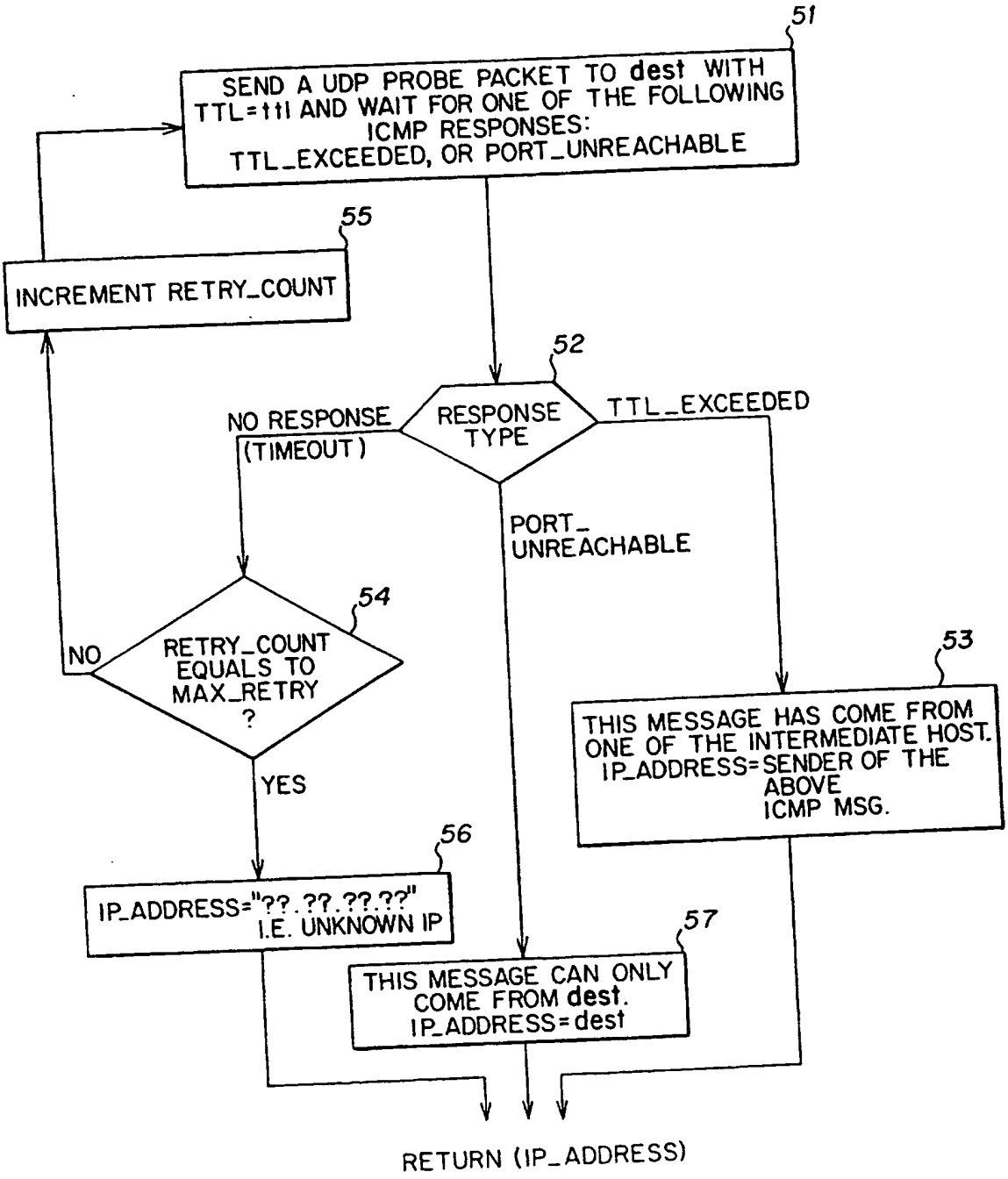
51
SEND A UDP PROBE PACKET TO dest WITH TTL=ttl AND WAIT FOR ONE OF THE FOLLOWING ICMP RESPONSES: TTL_EXCEEDED, OR PORT_UNREACHABLE
55
INCREMENT RETRY_COUNT
52
RESPONSE TYPE
NO RESPONSE (TIMEOUT)
TTL_EXCEEDED
PORT_ UNREACHABLE
54
NO
RETRY_COUNT EQUALS TO MAX_RETRY ?
YES
53
THIS MESSAGE HAS COME FROM ONE OF THE INTERMEDIATE HOST. IP_ADDRESS=SENDER OF THE ABOVE ICMP MSG.
56
IP_ADDRESS="??.??.??.??" I.E. UNKNOWN IP
57
THIS MESSAGE CAN ONLY COME FROM dest. IP_ADDRESS=dest
RETURN (IP_ADDRESS)

FIG. 3

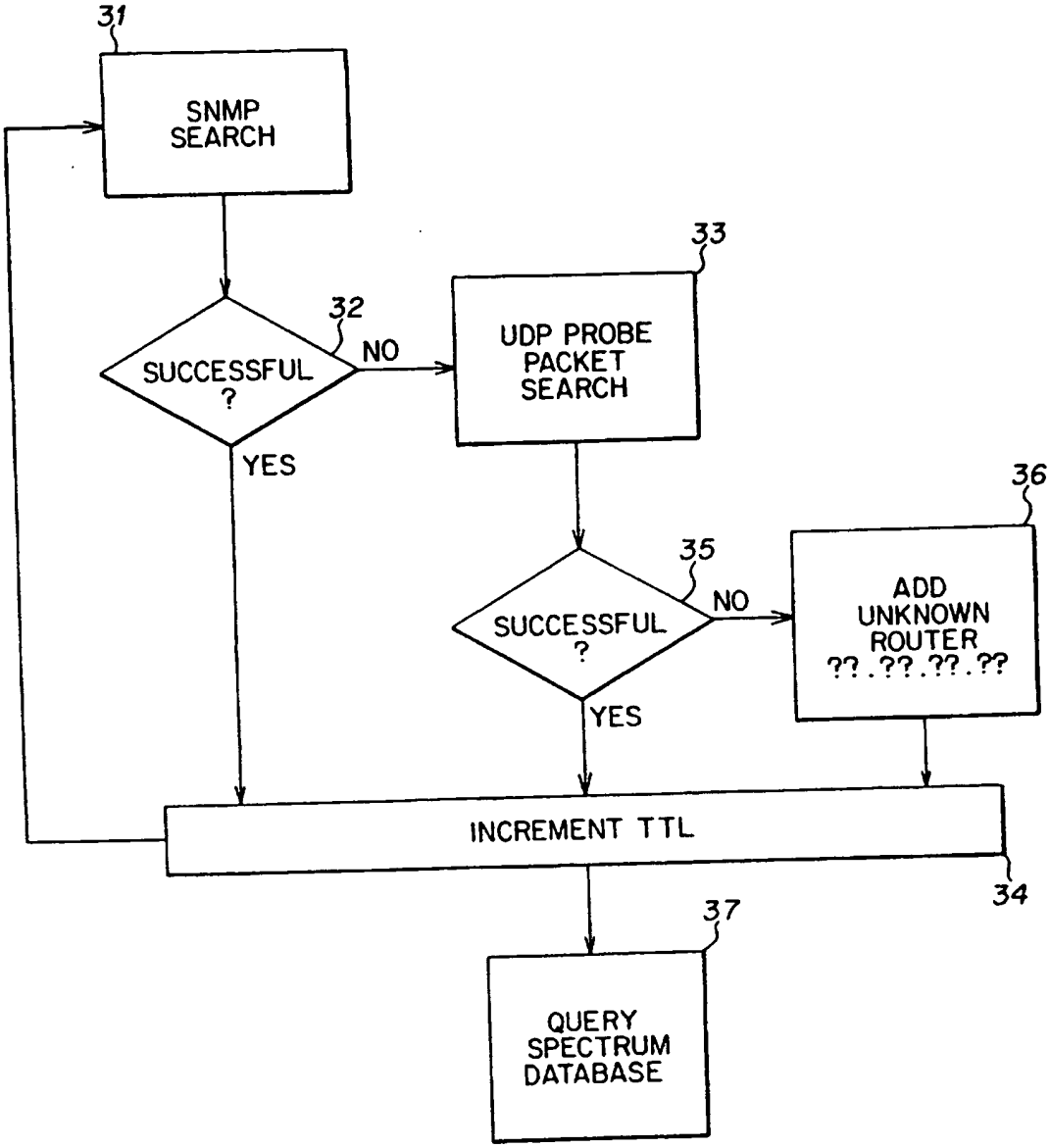
31
SNMP SEARCH
32
SUCCESSFUL ?
NO
YES
33
UDP PROBE PACKET SEARCH
35
SUCCESSFUL ?
NO
YES
36
ADD UNKNOWN ROUTER ??.??.??.??
INCREMENT TTL
34
37
QUERY SPECTRUM DATABASE

FIG. 4

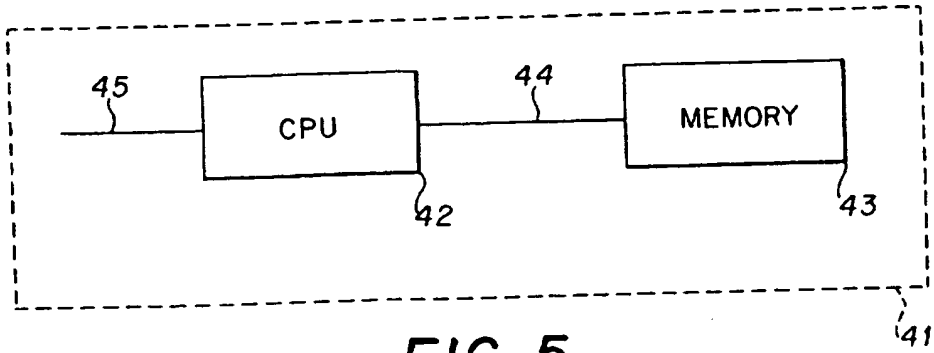
45
CPU
44
MEMORY
42
43
41

FIG. 5